(Neutrino indirect) detection of neutralino dark matter in (non) universals SUSY GUT models

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(Neutrino Indirect) Detection of Neutralino Dark Matter in (non-)Universals SUSY GUT Models.

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$\Rightarrow$ V.Bertin, E.N., J.Orloff, non-Universal models, hep-ph/0210034

$\Rightarrow$ V.Bertin, E.N., J.Orloff, hep-ph/0204135 accepted in EPJ C (mSugra)

see also: J.L.Feng, K.T. Matchev, F. Wilczek, PRD63(01)040524
V. Barger, F. Halzen, D. Hooper, C. Kao, PRD65(02)075022

and: L. Bergström, J. Edsjö, P. Gondolo; PRD58(98)103519
G. Jungman, M. Kamionkowski, K.Griest, Phys. Rep. 267 (96)

Contents

Detecting cold dark matter (WIMPS) in neutrino telescopes

mSugra summary

non-Universality :

- Scalar sector
- Gaugino sector

Conclusion

DM indirect detection with a neutrino telescope: ingredients

- ⋆ A cold dark matter canditate: choose χ, lightest neutralino in Constrained MSSM

- ⋆ A relic density: depends on (co-)annihilation processes σ_A

- ⋆ A cosmic storage ring: to re-start annihilation, need to concentrate n_χ; halo, clumps? too small for ν's! Need big, nearby, heavy body with large capture rate (C) $\Rightarrow$ depends on $\sigma^{el}_{\chi p}$. Sun: OK! Earth: small.

- ⋆ $\chi =$ Majorana fermion: can self-annihilate, limiting the total population N_χ:

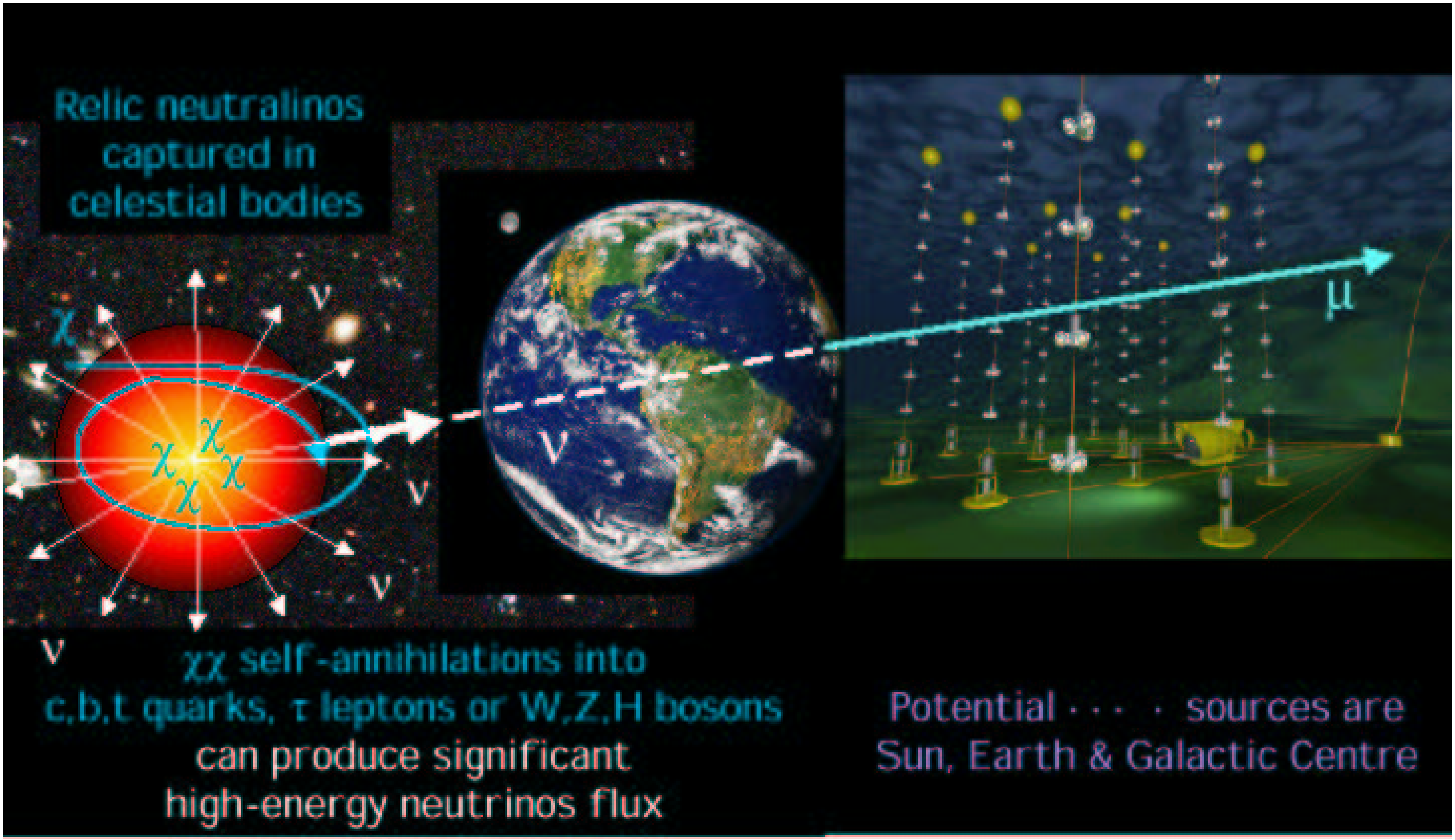
$$\dot{N}_\chi = C - C_A N_\chi^2$$

  Annihilation rate: $\Gamma_A = \frac{1}{2} C_A N_\chi^2 = \frac{C}{2} \tanh^2 \sqrt{C C_A} t \overset{eq}{\sim} \frac{C}{2}$ can be insensitive to σ_A

- ⋆ among decay products $\chi\chi \to b\bar{b}, t\bar{t}, WW, ZZ, \ldots \to \nu + \cdots$, only ν's can escape the sun and reach a detector. $\Phi(E_\nu)$ depends on dominant annihilation channel

- ⋆ Cerenkov detector watches for ν's converted into μ

DM indirect detection with a neutrino telescope: picture



Neutralino

SM $\xrightarrow{SUSY}$ MSSM

- group $SU(3) \times SU(2) \times U(1)$
- 2 Higgs doublets : $\tan\beta = \frac{v_u}{v_d}$, 5 scalars : h, A, H, $H^{\pm}$
- R-parity conservation $\longrightarrow$ stable LSP
- $m_p \neq m_{\tilde{p}} \Rightarrow$ Soft breaking terms $\mathcal{L}_{\rm soft}$

In the basis $(-i\tilde{B}, -i\tilde{W}^3, \tilde{H}_1^0, \tilde{H}_2^0)$:

$$M_\chi = \begin{pmatrix} M_1 & 0 & -m_Z c\beta sW & m_Z s\beta sW \\ 0 & M_2 & m_Z c\beta cW & -m_Z s\beta cW \\ -m_Z c\beta sW & m_Z c\beta cW & 0 & -\mu \\ m_Z s\beta sW & -m_Z s\beta cW & -\mu & 0 \end{pmatrix}$$

$$\chi = z_{11}\tilde{b} + z_{12}\tilde{W}^3 + z_{13}\tilde{H}_1^0 + z_{14}\tilde{H}_2^0$$

gaugino fraction : $f_G = z_{11}^2 + z_{12}^2$

higgsino fraction : $f_H = z_{13}^2 + z_{14}^2$

mSugra/CMSSM models

Parameters at GUT scale $\sim 2.\,10^{16}$ GeV:

⋆ a common gaugino mass $m_{1/2}$
⋆ a common scalar mass m_0
⋆ a common trilinear coupling A_0
⋆ a common bilinear coupling B_0
⋆ Higgs parameter μ_0

+ Renormalization group equations and radiative ElectroWeak Symmetry Breaking:

$$\frac{1}{2}m_Z^2 = \frac{m_{H_d}^2\Big|_{Q_{EWSB}} - m_{H_u}^2\Big|_{Q_{EWSB}} \tan^2\beta}{\tan^2\beta - 1} - \mu^2|_{Q_{EWSB}}$$

achieved at $Q_{EWSB} \sim \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$

$\Rightarrow$ Input parameters :

$$m_0, m_{1/2}, A_0, \tan\beta, sgn(\mu)$$

Advantages: REWSB, less free parameters, contact with acc. analyses, but also addressing CCB, Landau poles, high energy extrapoll.
Thanks to Suspect authors
http://www.lpm.univ-montp2.fr:7082/ kneur/suspect.html
(study of the CMSSM with Suspect :
hep-ph/0107316, A. Djouadi, M. Drees,J.L. Kneur)

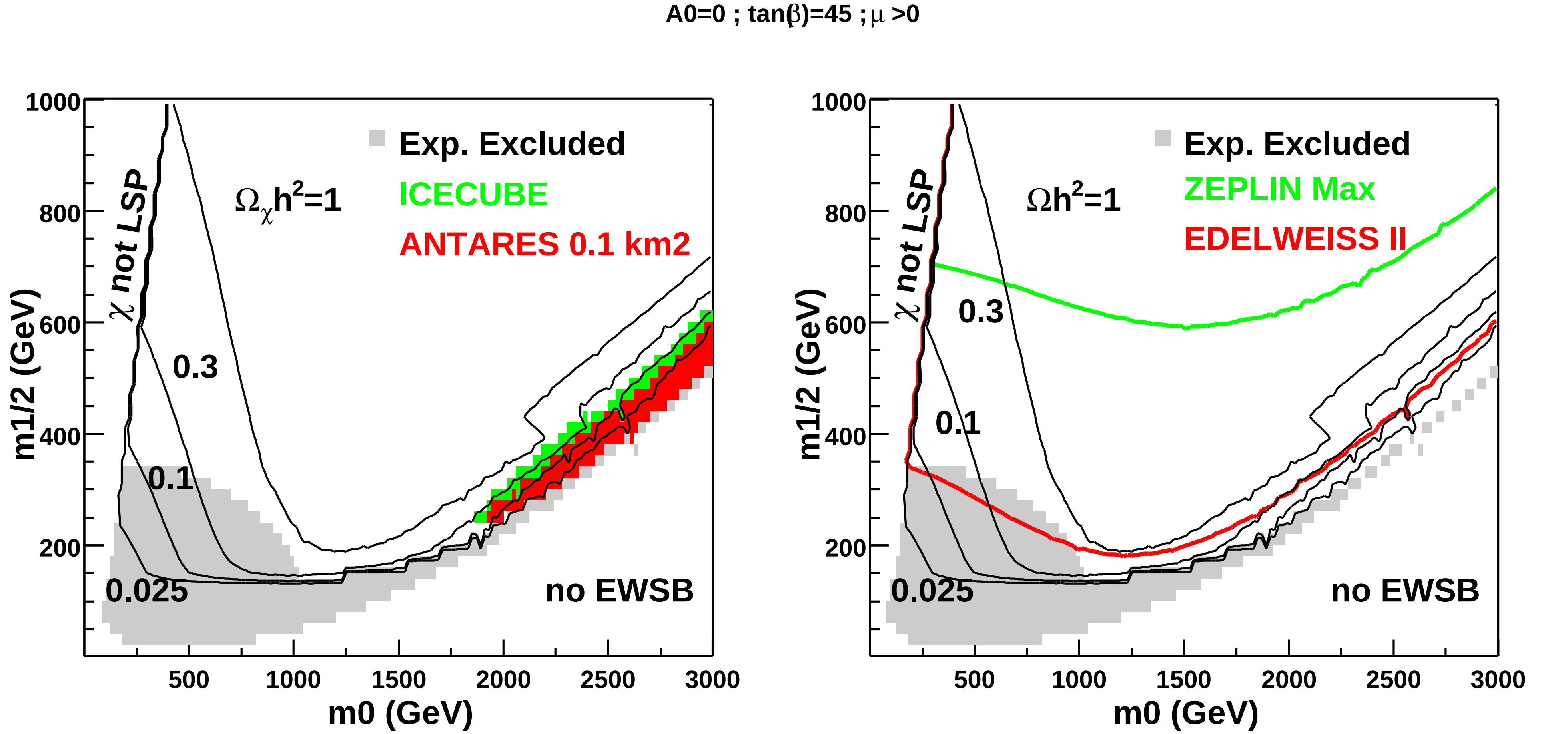
Composition of the lightest neutralino :

⋆ bino χ : for low m_0, RGE drive

$$M_1|_{Q_{EWSB}} = \frac{M_2|_{Q_{EWSB}}}{2} = 0.41 m_{1/2} << |\mu|_{Q_{EWSB}}$$

⋆ mixed bino-higgsino χ : EWSB $\sim -m_{H_u}^2|_{Q_{EWSB}} - \mu^2|_{Q_{EWSB}}$ if $\tan\beta \geq 5$
for m_0 large (> 1000),
increasing $m_0 \Rightarrow m_{H_u}^2$ less negative $\Rightarrow \mu$ decreases $\Rightarrow \mu \sim M_1$
"Focus point region" hep-ph/9909334 Feng, Matchev, Moroi

Experiment sensitivities in the $(m_0, m_{1/2})$ plane



$$A_0 = 0\ ;\ \tan\beta = 45\ ;\ \mu > 0$$

Calculation with Suspect + Darksusy package :

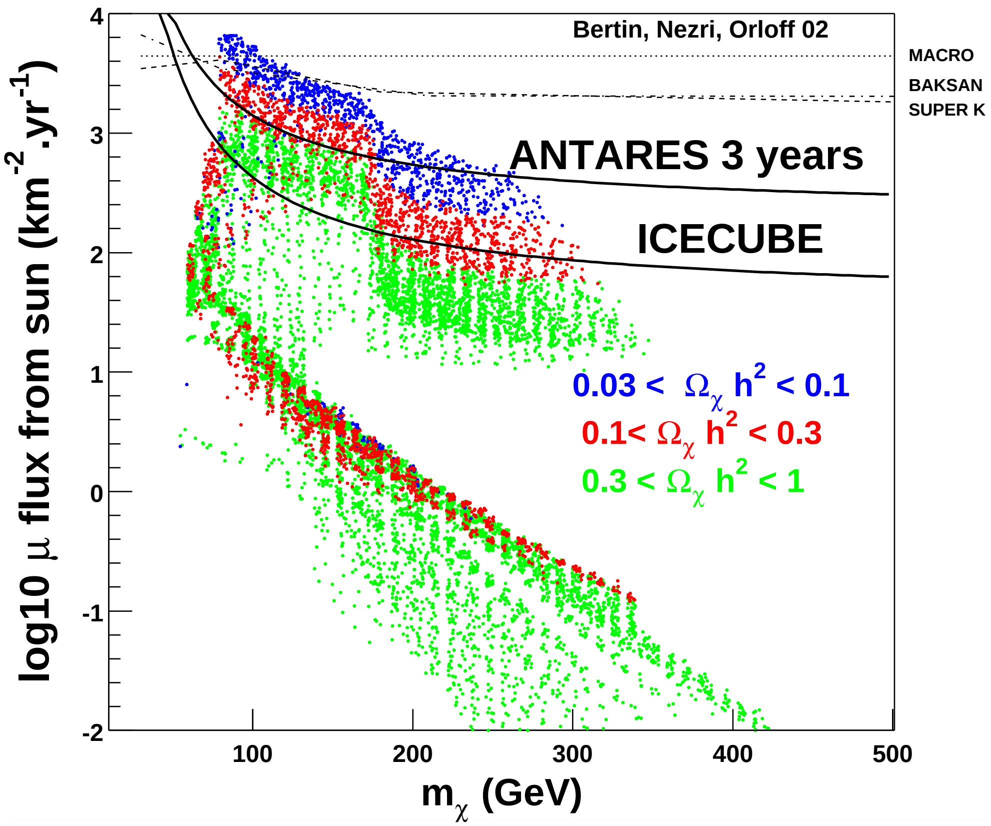
http://www.lpm.univ-montp2.fr:7082/ kneur/suspect.html

http://www.physto.se/ edsjo/darksusy/

mSugra : Direct Detection Experiments vs Neutrino Telescopes

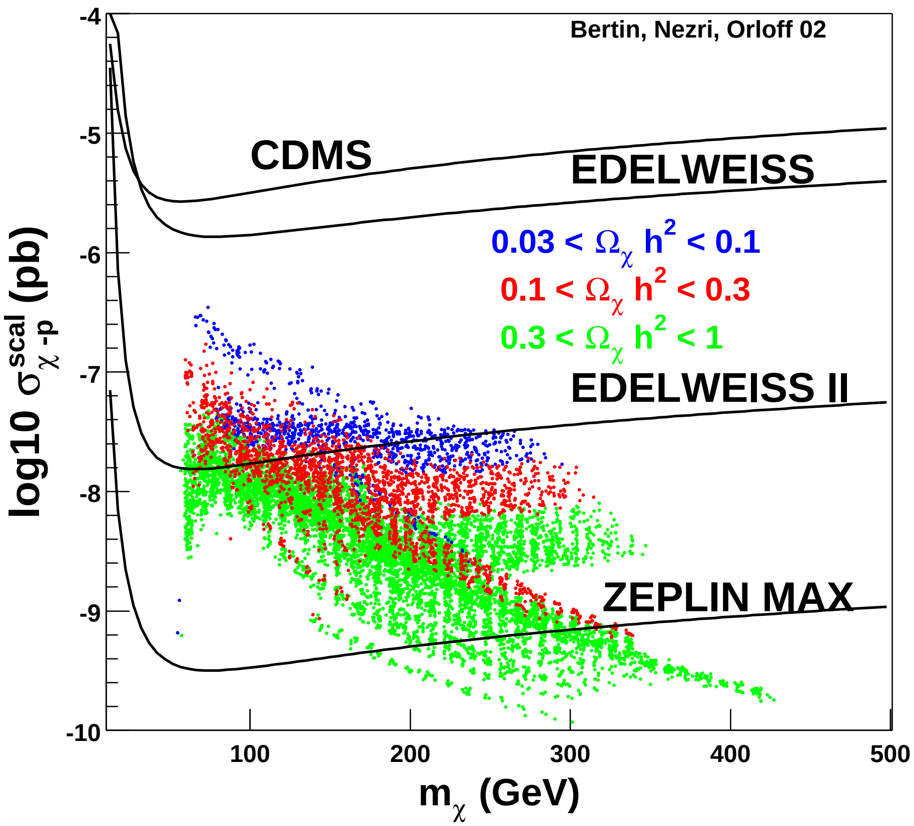
μ flux$_\odot$: m_χ

mSugra with 5 GeV threshold vs neutrino Indirect Dection



$\sigma^{scal}_{\chi-p}$: m_χ

mSugra models vs Direct Detection

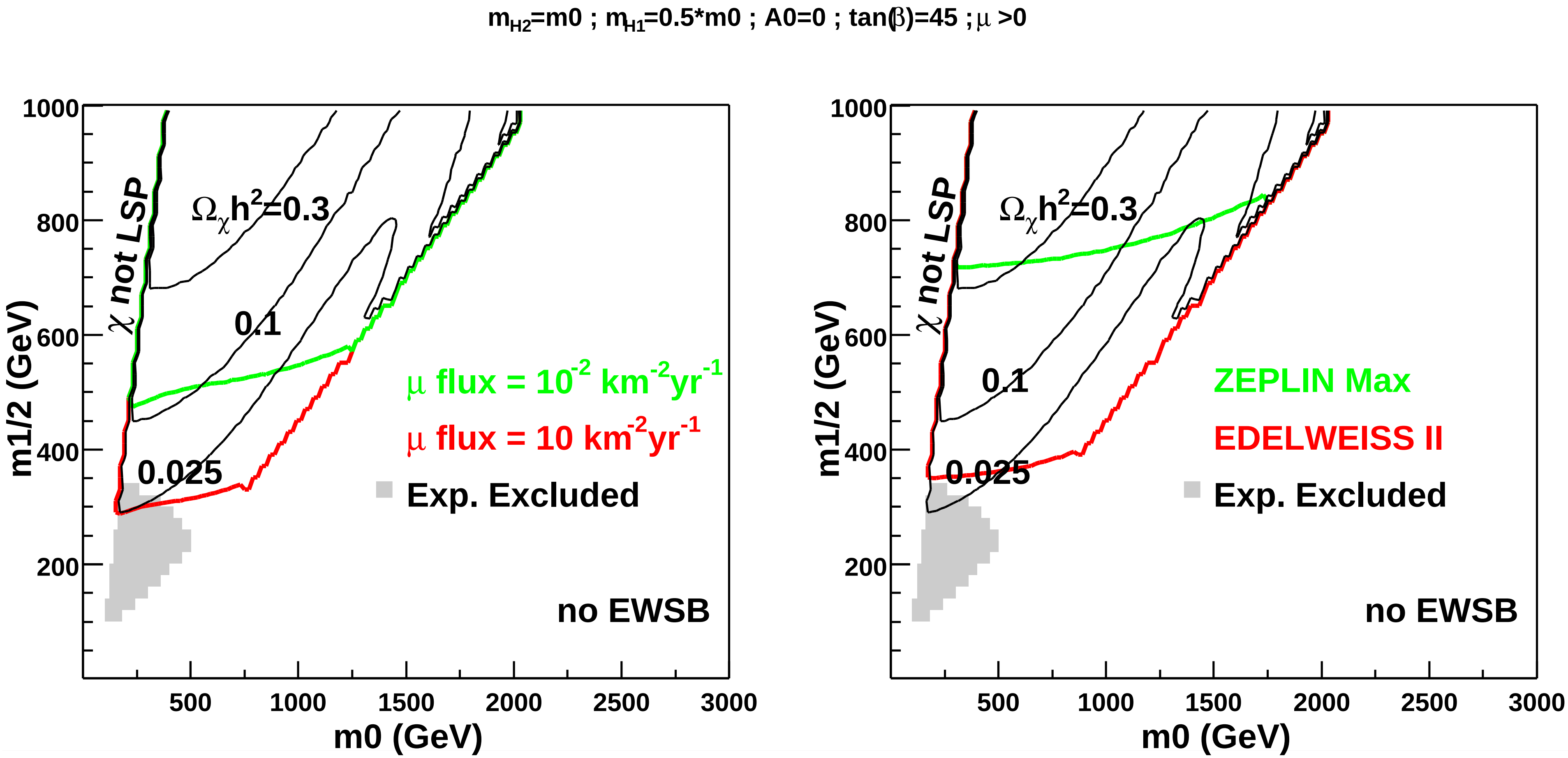


Non-universal scalar soft terms

- ⋆ Sfermions : non-universality in sfermions matrices can lead to light third generation sfermions $\rightarrow$coannihilations $\chi\tilde{\tau},\ \chi\tilde{t}$ can modify the relic density but happend in region out of reach of detectors. Detection imply "real" quarks mainly on u and d valence and due to their low Yukawa couplings RGE evolutions of the first and second generation squarks depend on gaugino soft masses $\longrightarrow$ their masses can not be lowered by changing scalar soft terms to enhance $\sigma^{scal}_{\chi-q}$ and $\sigma^{spin}_{\chi-q}$ through the process $\chi q \xrightarrow{\tilde{q}} \chi q$.

- ⋆ Higgses : relax universality $m_{H_i}|_{M_{GUT}} = (1+\delta_i)m_0 \longrightarrow$ modify REWSB relation parameters , m_A, μ can change life.

non universal Higgs masses effects in the $(''m_0'', m_{1/2})$ plane



$$m_{H_2} = m_0 \; ; \; m_{H_1} = 0.5 m_0 ; \; A_0 = 0 \; ; \; \tan\beta = 45 \; ; \; \mu > 0$$

⋆ wider noREWSB region ⋆ $m_{A(H)} < m_{A(H)}|_{mSugra} \rightarrow$ good for relic density ($\chi\chi \xrightarrow{A} b\bar{b}$) and direct detection at low m_0 ($\chi q \xrightarrow{H} \chi q$) ⋆ but lower indirect detection $\neq$ Barger et al PRD65 2002, due to the low Isajet value of μ at high m_0 (Allanach, Kraml, Porod, SUSY 02, hep-ph/0207314) which increases the higgsino fraction (?).

Free relations in gaugino mass parameters

$M_2|_{GUT}$ parameter

- ⋆ essentially modify neutralino composition (and slightly low energy values of fields whitout $SU(3)$ charge through RGE).
  Increasing the wino component of the neutralino favours $\rightarrow$ $\chi\chi \xrightarrow{\chi_1^+,\ \chi_2^0} W^+W^-,\ ZZ$ and enhance the annihilation cross section $\sigma^A_{\chi-\chi}$. the strong $\chi\chi_2^0$ and $\chi\chi_1^+$ coannihilations become actives and $\Omega_\chi h^2$ strongly decreases.
- ⋆ larger coupling entering in $\sigma^{scal}_{\chi-p}$ $\rightarrow$ increases the direct detection
- ⋆ favours neutralino annihilations into the hard W^+W^- spectrum$\rightarrow$ increases the indirect detection muon fluxes
- ⋆ However, the relevant value of M_2 is very critical : = fine-tunning (except moduli decays giving wino in AMSB models. Moroi, Randall hep-ph/9906527).

$M_3|_{GUT}$ parameter

⋆ 1-loop RGE analyse $\rightarrow$ $M_3|_{GUT}$ is the main parameter for non-universality in the MSSM (Kazakov, Moultaka hep-ph/9912271).
$(M^{scal}_{soft}|_{low})^2 = (M^{scal}_{soft}|_{GUT})^2 + c_3 f_3 + c_2 f_2 + c_1 f_1 + corrections$
with $f_i = \frac{(M_i^{GUT})^2}{b_i}\left(1 - \frac{1}{(1+b_i\alpha_0 t)^2}\right)$
and c_3 strongly dominant.
$\rightarrow$ $M_3|_{GUT} < m_{1/2}$ decreases m_A, $m^2_{H_2}$, μ (and $m_{\tilde{q}}$)

⋆ increase annihilation
$\chi\chi \xrightarrow{A} b\bar{b}$ $\quad(\chi\chi \xrightarrow{\tilde{f}} f\bar{f})$

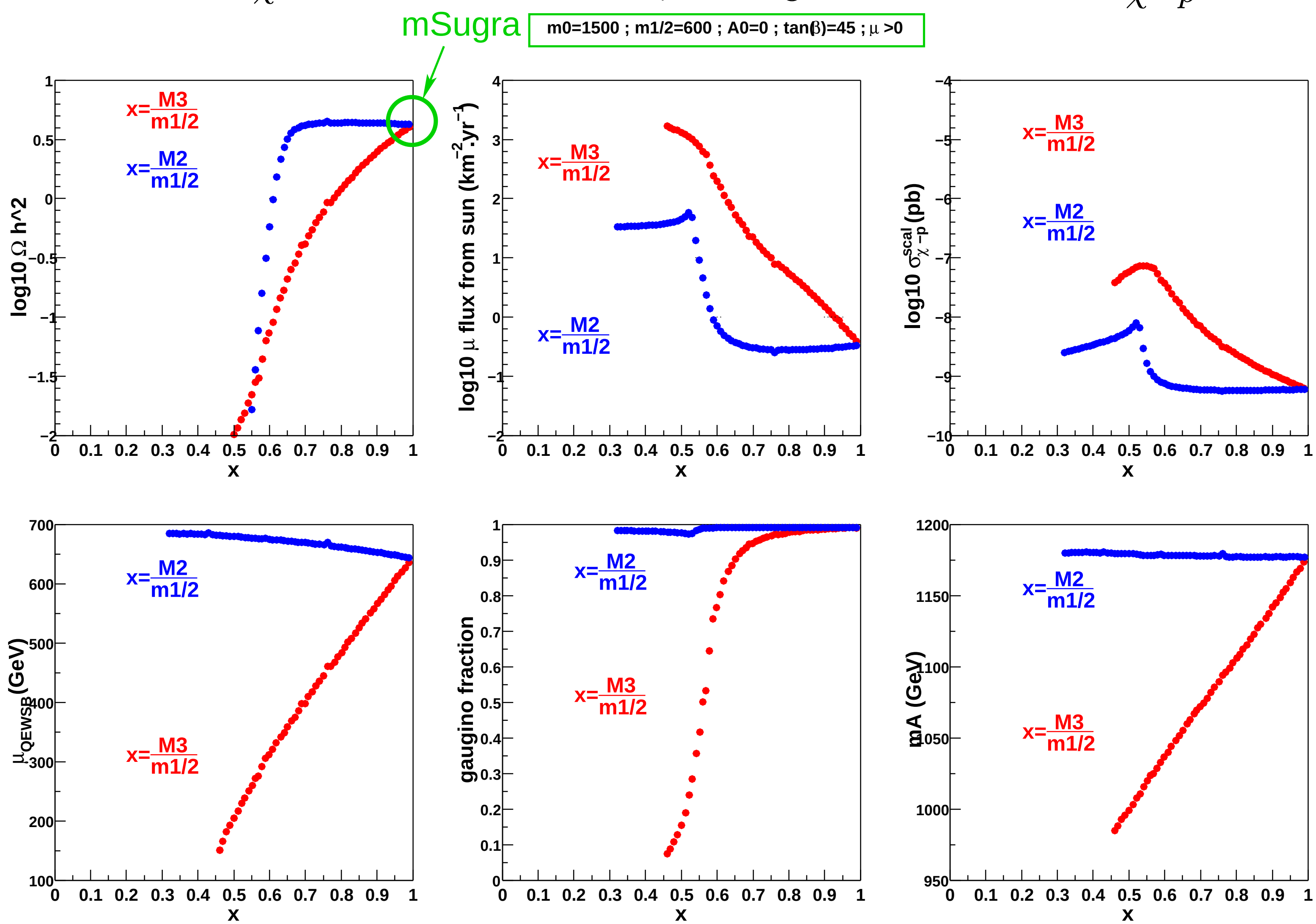
$\chi\chi \xrightarrow{Z} t\bar{t}$, $\chi\chi \xrightarrow{\chi_i^+,\chi_i} W^+W^-,\ ZZ \propto$ higgsino fraction
$\rightarrow$ very favourable for $\Omega_\chi h^2$

Gain for detection :

⋆ direct detection : increase $\sigma^{scal}_{\chi-p}$ via $\chi q \xrightarrow{H} \chi q$ (m_H lower and $z_{11(2)}z_{13(4)}$ $\nearrow$)
⋆ indirect detection : increase capture $\sigma^{spin}_{\chi-p}$ via $\chi q \xrightarrow{Z} \chi q$ (higgsino fraction $\nearrow$) and annihilation $\chi\chi \rightarrow W^+W^-,\ ZZ,\ t\bar{t}$ with energetic neutrinos

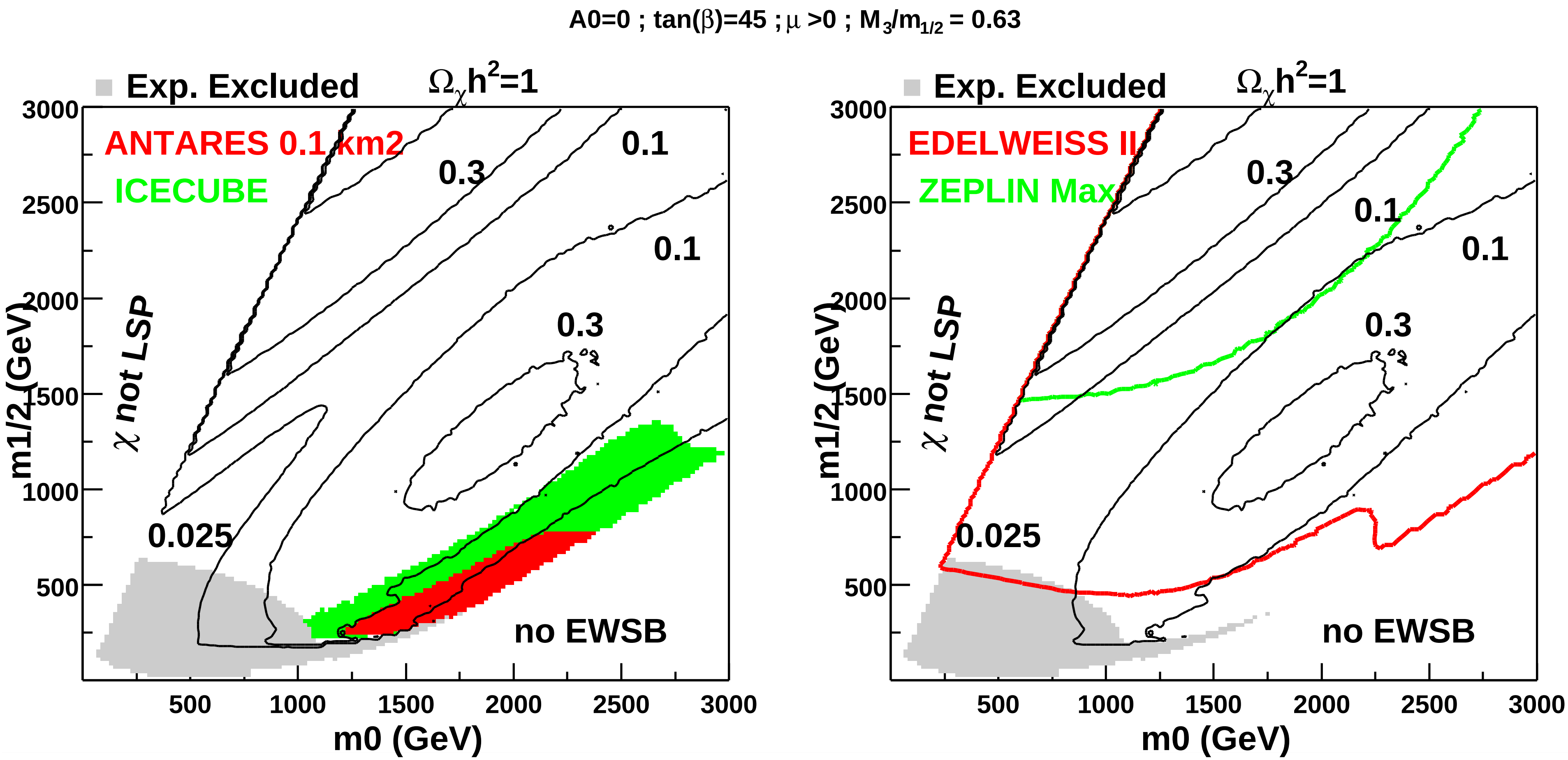
Effects of $x = \frac{M_{3(2)}|_{GUT}}{m_{1/2}}$ on relic density and detection rate

$\Omega_\chi h^2$ $\quad$ μ flux$_\odot$ $\quad$ $\sigma^{scal}_{\chi-p}$



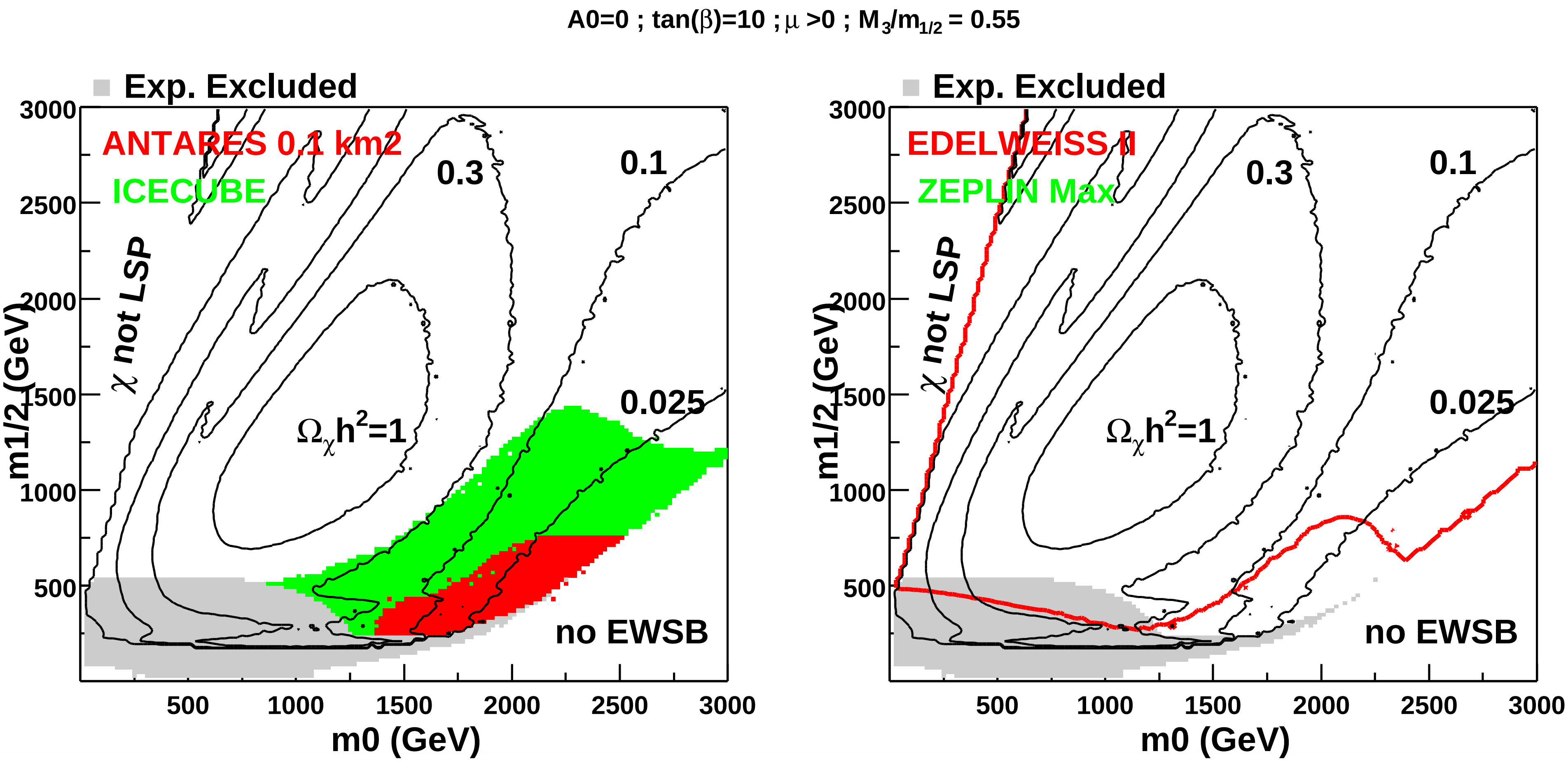
μ $\quad$ f_G $\quad$ m_A

$M_3|_{GUT}$ effect on experiment sensitivities in the $(m_0,'' m''_{1/2})$ plane



$$\frac{M_3|_{GUT}}{m_{1/2}} = 0.63 \text{ ; } \tan\beta = 45$$

$M_3|_{GUT}$ effect on experiment sensitivities in the $(m_0,'' m''_{1/2})$ plane



$$\frac{M_3|_{GUT}}{m_{1/2}} = 0.55 \; ; \tan\beta = 10$$

Conclusion

RGE models OK with neutrino indirect detection :

⋆ very heavy scalars (beyond reach of LHC)

⋆ neutrino telescope signal in mSugra $\rightarrow m_{\chi^+} < 300 - 350$ GeV

⋆ $\Omega h^2 \sim 0.15$ can be accomodated for all "mSugra" points using $x = M_3|_{GUT}/m_{1/2} \sim 0.6(\pm 0.1) + \mathrm{corrections}(m_0, \tan\beta, m_b)$ with a strong enhancement of detection rates improving the experiment possibilities.

⋆ Earth out of reach neutrino telescopes in those framework.

⋆ These models are compatible with the Standard Model value of $(g-2)_\mu$: $a_\mu^{SUSY} \simeq 0$.